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TDR-594(1430)TN-1

Revised Overpressure Curves for Liquid Oxygen and RP-1

24 MARCH 1961

Prepared by W. M. SMALLEY

Prepared for DEPUTY COMMANDER AEROSPACE SYSTEMS
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Inglewood, California

AEROSPACE CORPORATION
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W. M. Smalley

AEROSPACE CORPORATION
El Segundo, California

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PREFACE

This report was originally issued as an interoffice memorandum, AS 1924-109 (24 March 1961). There are no changes in the technical content.

ABSTRACT

Revised overpressure curves for liquid oxygen RP-1 missile explosions have been developed. The overpressure is presented as a function of the total propellant weight and the distance from the explosion.

REVISED OVERPRESSURE CURVES FOR LIQUID OXYGEN AND RP-1

A method* was developed in 1959 for determining overpressure-distance-weight relationships for liquid oxygen and RP-1 explosions. At that time, overpressure data were available on missile explosions of various sizes up to approximately 100,000 pounds of propellant. Since that time, additional data have become available on three Atlas explosions, each involving approximately 250,000 pounds of propellant.

It is the purpose of this report to develop revised overpressure curves to include new data and utilize additional analytical techniques necessitated by the greater asymmetry in the new data.

Analysis is complicated by the fact that recently some question has been raised as to the correct calibration factor to be applied to the Pan American peak pressure gages used at Atlantic Missile Range. It was originally believed, as a result of shock tube calibrations at Ballistic Research Laboratories, that these gages read 1.35 times the true side-on pressure in their face-on orientation. However, at the 20-ton TNT test held in Canada last summer, the PAA gage read only 1.1 times the side-on pressure. Pan American now states that the gage readings lie between 1.1 and 1.35 times the true side-on pressure. Since this applies to all full-scale data, it will have a pronounced effect on the results of this analysis. Therefore, a dual analysis will be made, one using the 1.35 correction factor, the other the 1.1 correction factor.

For each gage reading at a given distance, an equivalent overpressure reading at 1000 feet, designated P_{1000}, was determined. (It should be pointed out that P_{1000} is arbitrary, only used as a transfer point in the calculations to eliminate the distance variable. Results would be the same if some other distance, e.g., 2000 feet, were chosen.) The individual readings were then averaged

*W. M. Smalley and D. E. Anderson, "The Explosive Potential of Liquid Oxygen and RP-1 Missiles" (Confidential), Space Technology Laboratories, Inc., GM-TR-59-0000-00579, 30 January 1959.

to give a mean pressure, $\overline{P}_{1000}$, for each shot. Mean pressure was used to insure against weighting any one shot merely because more gage readings might have been taken. It is recognized, however, that using the mean pressure only does not take into consideration the variation about the mean for each individual shot. This factor will be discussed separately and a method developed to permit the prediction of the expected peak overpressure.

1.35 Correction Factor

Overpressure data from full-scale explosions are based on the 1.35 correction factor and will be used throughout this portion of the discussion. The effect of the 1.1 correction factor will be analyzed separately. The mean pressure at 1000 feet, $\overline{P}_{1000}$, has been plotted for each shot as a function of weight (Fig. 1).

The standard equation for a free air (AB) TNT explosion at large distances ($P < 1.0$ psi) is:

$$P_{AB} = 82.5\, Z^{-1.2}$$

where

P_{AB} = side-on overpressure for an air burst, psi

$Z = \dfrac{R}{W^{1/3}}$

R = distance, ft

W = weight of TNT, lb .

Using the 2W assumption for a surface burst (SB), the equation becomes:

$$P_{SB} = 108.86\, Z^{-1.2} \quad .$$

Similarly, for $P > 1.0$ psi the equation takes the form:

$$P_{SB} = \frac{4204}{Z^3} + \frac{276.4}{Z^2} + \frac{42.58}{Z} \quad .$$

In both equations the decay of overpressure with distance is described as a function of $R/W^{1/3}$. In the case of liquid oxygen and RP-1, overpressure could be described as a function of R/aW^n, with a and n to be determined by a regression analysis. The overpressure from a surface burst of TNT for $P < 1.0$ psi is:

$$P_{TNT} = 108.86 \left(\frac{R}{W^{1/3}}\right)^{-1.2}$$

then for lox-RP, ($P < 1.0$ psi):

$$P_{LRP} = 108.86 \left(\frac{R}{aW^n}\right)^{-1.2}$$

$$= \frac{108.86\, a^{1.2}\, W^{1.2n}}{R^{1.2}} \quad .$$

Similarly, for $P > 1.0$ psi:

$$P_{LRP} = \frac{4204}{\left(\frac{R}{aW^n}\right)^3} + \frac{276.4}{\left(\frac{R}{aW^n}\right)^2} + \frac{42.58}{\left(\frac{R}{aW^n}\right)} \quad .$$

Then, at a distance of 1000 feet, for lox-RP:

$$P_{1000} = \frac{108.86\, a^{1.2}\, W^{1.2n}}{1000^{1.2}} \quad ,$$

$$P_{1000} = 0.027343a^{1.2}\, W^{1.2n} \quad .$$

Let

$$A = 0.027343a^{1.2}$$

$$B = 1.2n$$

then

$$P_{1000} = AW^{B} \quad ,$$

or

$$\log P_{1000} = \log A + B \log W \quad .$$

A linear regression analysis of $\log \bar{P}_{1000} = \log A + B \log W$, was carried out as follows based upon the data plotted in Fig. 1, where $Y = \log \bar{P}_{1000}$ and $X = \log W$.

$$N = 34$$

$$\Sigma Xi = 87.21988$$

$$\Sigma Yi = -42.02117$$

$$\Sigma XiYi = -85.11594$$

$$\Sigma Xi^2 = 291.57749$$

$$\Sigma Yi^2 = 60.88369$$

$$\bar{X} = 2.56529$$

$$\bar{Y} = -1.23592$$

$$s_x^2 = \frac{\Sigma Xi^2 - \frac{(\Sigma Xi)^2}{N}}{N - 1} = 2.05555$$

$$s_y^2 = \frac{\Sigma Yi^2 - \frac{(\Sigma Yi)^2}{N}}{N - 1} = 0.27118$$

$$B = \frac{\Sigma XiYi - \frac{\Sigma Xi \, \Sigma Yi}{N}}{\Sigma Xi^2 - \frac{(\Sigma Xi)^2}{N}} = 0.33436$$

$$n = \frac{B}{1.2} = 0.2786$$

$$\log A = \overline{Y} - B\overline{X} = -2.09365$$

$$A = 0.0080602$$

$$a^{1.2} = \frac{0.0080602}{0.027343} = 0.29478$$

$$a = 0.36134 \quad .$$

Figure 1 shows the original data with curve A as the regression line. To establish certain confidence limits about this curve, two additional steps must be taken. First, the variance $\sigma_{y.x}^2$ of the original data about the regression line, based upon $\overline{P}_{1000}$ must be determined. An unbiased estimate of $\sigma_{y.x}^2$ is $s_{y.x}^2$, where

$$s_{y.x}^2 = \frac{N - 1}{N - 2} (s_y^2 - B^2 s_x^2) = 0.042673 \quad .$$

The effect of this variance at the 98 percent confidence limit is drawn as curve B in Fig. 1. In addition, the variation between individual gage readings on any one shot must be taken into consideration. This was done by first calculating the variance, s_i^2, between gage readings for each shot. These individual variances must then be combined. An unbiased estimate of the pooled variances, σ_p^2, of the individual shots is s_p^2, where

$$s_p^2 = \frac{(n_i - 1)\, s_i^2}{N - k} = 0.0055975$$

s_i^2 = variance for one individual shot

n_i = number of gage readings per shot

N = total number of all gage readings

k = number of shots .

The total variance is then the sum of the two, or

$$\sigma^2 = s_{y.x}^2 + s_p^2 = 0.04827$$

$$\sigma = 0.21970 \quad .$$

Thus, this value of the standard deviation about the mean regression takes into consideration both the shot-to-shot variation and the individual asymmetries of each shot. This means, then, that any confidence limits about the mean regression curve will refer to the expected individual pressures rather than to the average of the pressures about the missile. The effect of this combined variance at the 98 percent confidence limit is shown as curve C in Fig. 1.

Using the values of a and n previously determined, the equations for the peak side-on overpressure to be expected from a liquid oxygen RP-1 explosion at the 98 percent confidence limit are:

for $P > 1.0$ psi:

$$P_{+98} = \frac{3758}{Z^3} + \frac{256}{Z^2} + \frac{41}{Z}$$

for $P < 1.0$ psi:

$$P_{+98} = 104\,Z^{-1.2}$$

where

$$Z = \frac{R}{W^{0.279}} \quad .$$

The curve of P_{+98} versus $R/W^{0.279}$ is shown as the upper curve in Fig. 2. The lower curve represents the mean regression curve and has the following equations:

for $P > 1.0$ psi:

$$P = \frac{198}{Z^3} + \frac{36}{Z^2} + \frac{15.4}{Z}$$

for $P < 1.0$ psi:

$$P = 32.1\,Z^{-1.2}$$

where

$$Z = \frac{R}{W^{0.279}} \quad .$$

These equations have been used to determine the pressure-distance relationship for 250,000 pounds of liquid oxygen and RP-1; this value is shown in Fig. 3 with the lower curve representing the predicted average of the pressures about the explosion and the upper curve representing the predicted peak pressure about the missile at the 98 percent confidence limit. This means, of course, that the peak pressure from a missile explosion could be expected to exceed the upper curve one percent of the time.

1.1 Correction Factor

When the 1.1 correction factor is applied to the full-scale data, significantly different results are obtained, as shown by the corresponding curves in Figs. 4, 5, and 6. The equations for the expected peak pressure at the 98 percent confidence limit are:

for $P > 1.0$ psi:

$$P_{+98} = \frac{3016}{Z^3} + \frac{221}{Z^2} + \frac{38.1}{Z}$$

for $P < 1.0$ psi:

$$P_{+98} = 95.3\,Z^{-1.2}$$

$$P = 32.1\,Z^{-1.2}$$

where

$$Z = \frac{R}{W^{0.3}} \quad .$$

Similarly, equations for the predicted average of the pressures about the explosion are:

for $P > 1.0$ psi:

$$P = \frac{158}{Z^3} + \frac{31}{Z^2} + \frac{14.3}{Z}$$

for $P < 1.0$ psi:

$$P = 29.3\, Z^{-1.2}$$

where

$$Z = \frac{R}{W^{0.3}} .$$

In order to more readily compare the effect of the two gage correction factors, the upper 98 percent confidence limit curves from Figs. 3 and 6 for 250,000 pounds of propellant have been replotted in Fig. 7. It is quite apparent that this area of uncertainty in the gage correction factor has a significant effect on the results of the analysis.

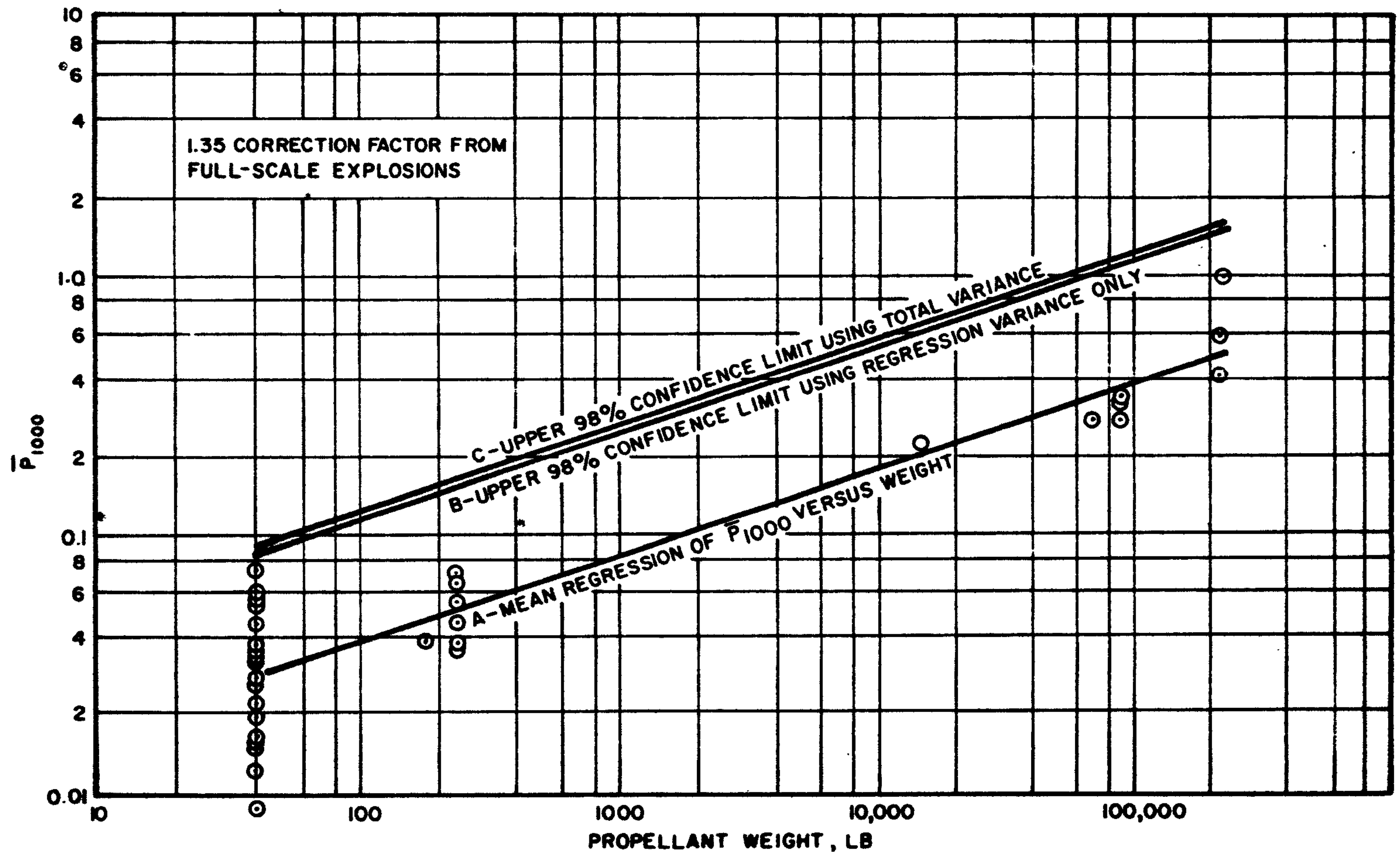

Fig. 1. Mean pressure at 1000 feet, $\bar{P}_{1000}$ versus propellant weight.

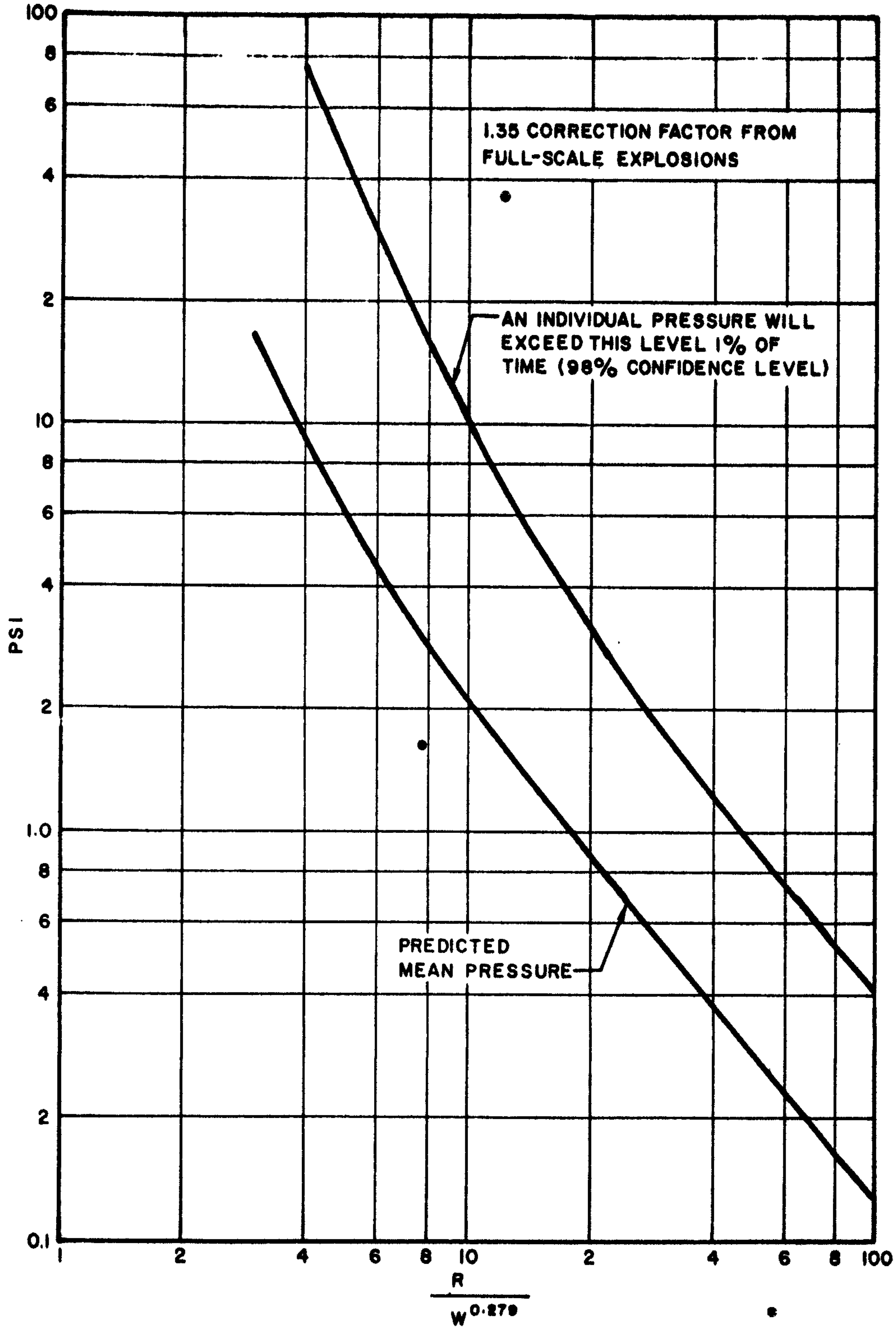

Fig. 2. Predicted overpressure, psi versus $\frac{R}{W^{0.279}}$.

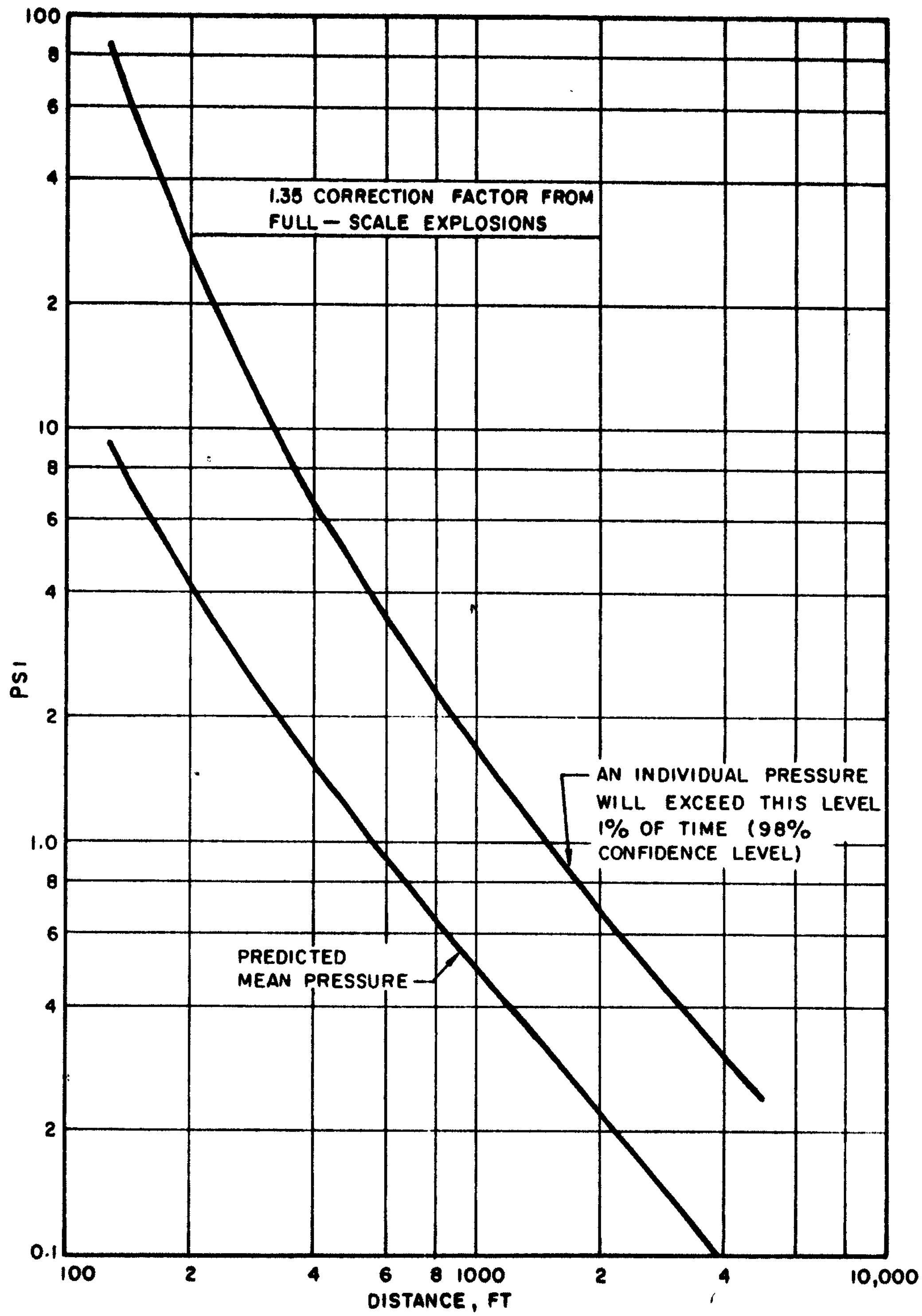

Fig. 3. Predicted overpressure, psi versus distance, for 250,000 pounds of propellant.

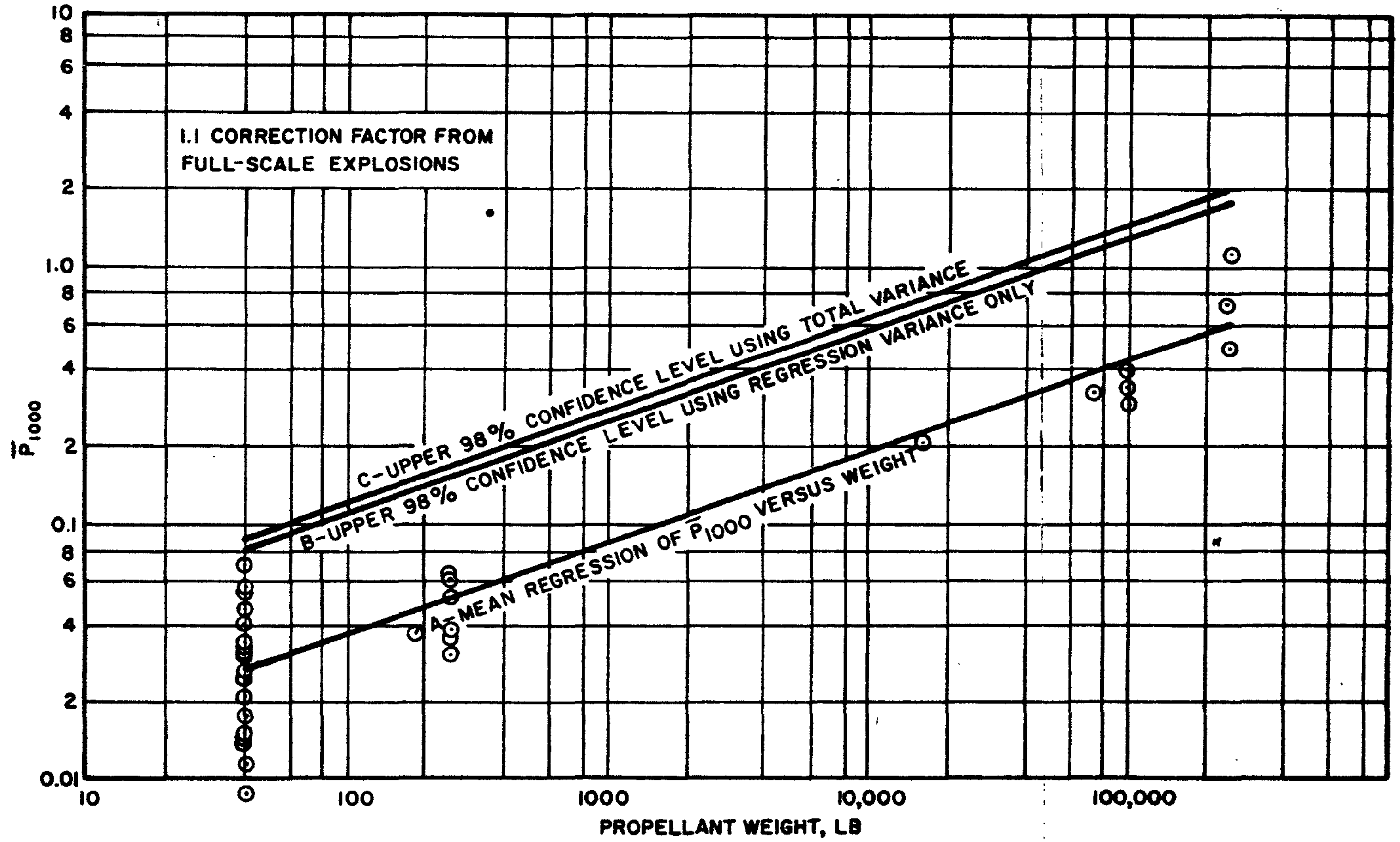

Fig. 4. Mean pressure at 1000 feet, $\overline{P}_{1000}$ versus propellant weight.

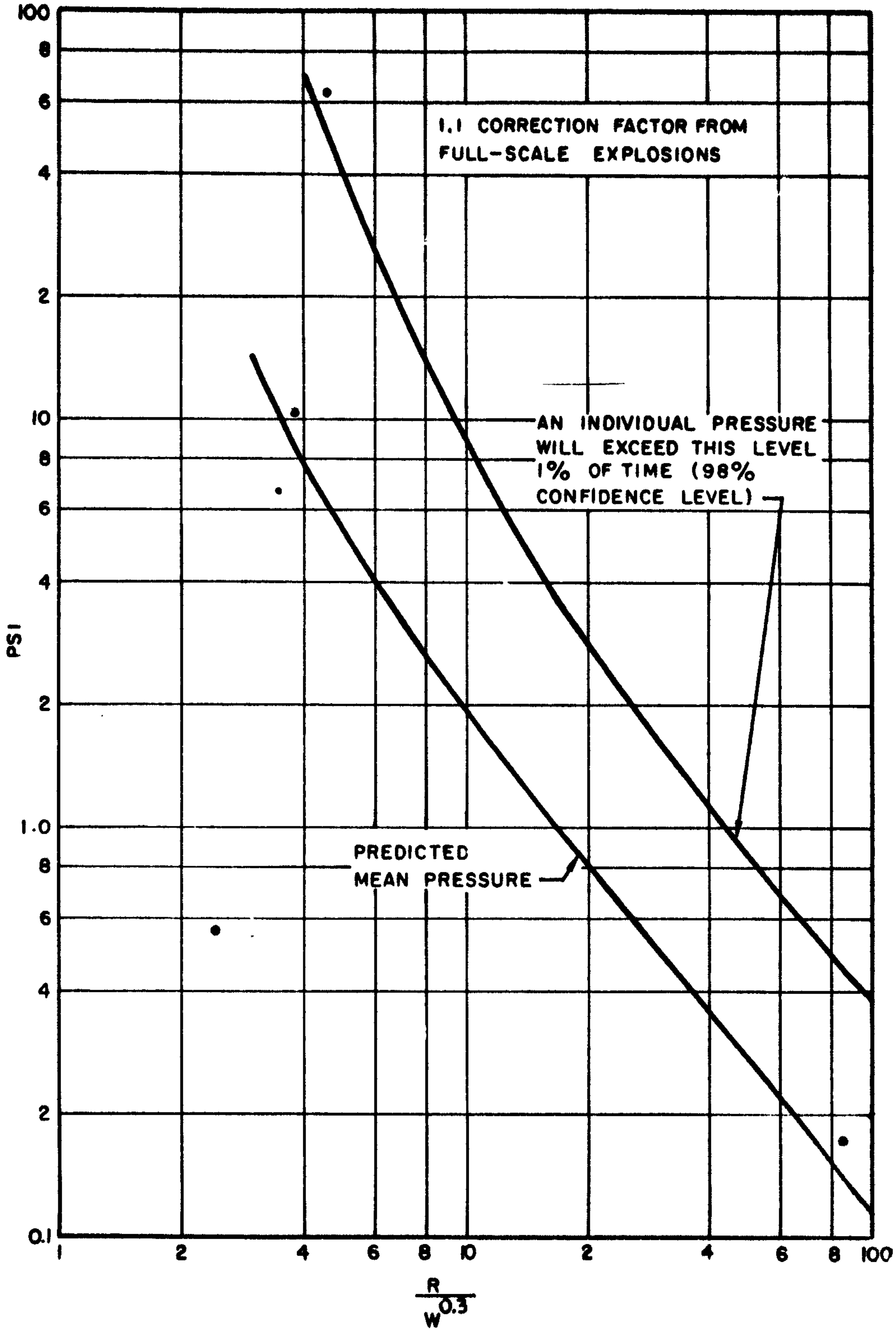

Fig. 5. Predicted overpressure, psi versus $\frac{R}{W^{0.3}}$.

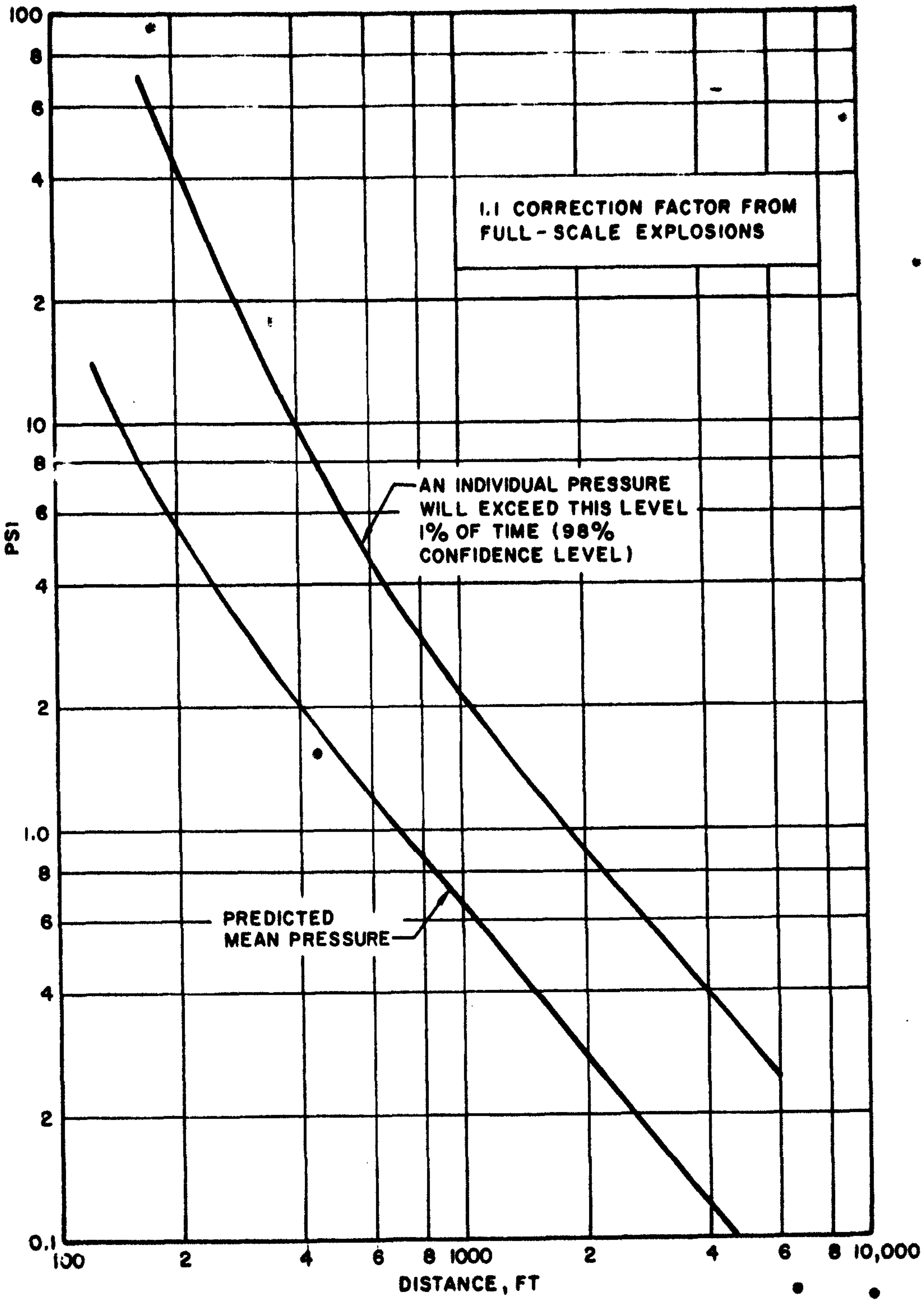

Fig. 6. Predicted overpressure, psi versus distance, for 250,000 pounds of propellant.

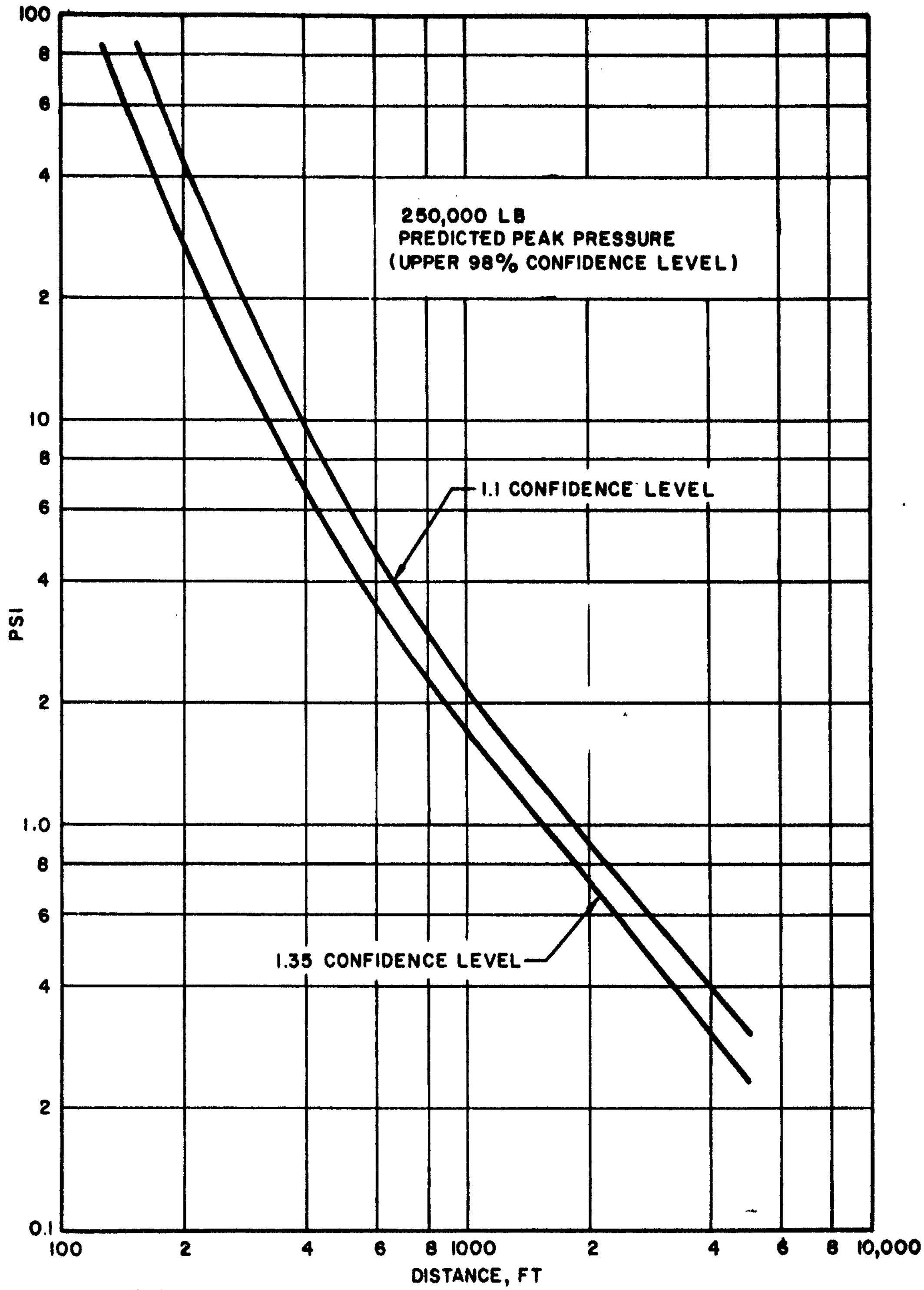

Fig. 7. Comparison of effect of 1.35 and 1.1 correction factors.

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